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Description

Computer-aided method for parallel calculation of the operating point of electrical circuits

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The computer-aided simulation of electrical circuits has attained increasing importance in the development of very large circuits, that is to say circuits having a very large number of elements. It is particularly in the development of computer chips having a multiplicity, for example several hundred thousand transistors, that serial processing for the determination of the circuit quantities by a computer has been found to be unusable because of the excessive time consumption.

15 In WO 98/24039, therefore, it is proposed to partition a large circuit and to have the partitions processed by different computers in each case.

20 In the calculation, the operating point, that is to say the potentials of all nodes is usually determined first as basis for further analyses such as, for example, transient or alternating-current analyses.

For the parallel calculation, an implementation of the Newton
25 method is proposed in U. Wever, Q. Zheng et al.: "Domain
Decomposition Methods for Circuit Simulation" (Proceedings of the
8th Workshop on Parallel and Distributed Simulation, PADS '94
Edinburgh, Scotland, UK, pp. 183-186, July 1994) and in U. Wever,
Q. Zheng: "Parallel Transient Analysis for Circuit Simulation"
30 (Proceedings of the 29th Annual Hawaii International Conference on
System Sciences, pp. 442-447, 1996). The disadvantage is that
convergence can only be achieved here when sufficiently good
estimates of the operating point are available, due to poor
convergence characteristics. As a rule, however, such good

estimates can be achieved with difficulty or not at all in the case of large circuits.

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as claimed in claim 1.

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the number of iteration steps necessary for the solution can then be used until the value drops below a predetermined value for "C".

Further advantageous embodiments of the invention are obtained
5 from the subclaims.

In the text which follows, the invention will be explained by means of an exemplary embodiment shown in the drawing. In the drawing, the single figure shows a flowchart which represents the
10 individual method steps of the method.

According to the drawing, a simulation of an electrical circuit is the starting point 1, for example in the circuit description language SPICE. This is partitioned in a first processing process
15 2, as described, for example, in WO 98/24039 as "Clustering method", so that individual partitions or parts of the circuits are obtained which can be calculated with the same degree of difficulty, if possible.

20 Naturally, other applicable variants of partitioning are conceivable such as, for example, the "ratio cut method" described in N. Fröhlich, B. Riess, U. Wever, Q. Zheng: "A new approach for parallel simulation of VLSI circuits on a transistor level" (IEEE Transaction on Circuits and Systems - I: Fundamental Theory and
25 Applications, Vol. 45, No. 6, June 1998, pages 601 to 613), or even an arbitrary "manual" division.

In a further process step 3, a grounded capacitance is added to each node of the circuit, that is to say to a junction of at least
30 two conductors or current paths, respectively. Naturally, it is also conceivable to add a capacitance, the second terminal of which is connected to a predetermined potential, in which case both potentials and values for the capacitances of each node

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can differ. For reasons of efficiency, stability and economy of calculation, each capacitance is connected to the same potential with its second terminal, for example ground, an identically high value C0 also being selected for all capacitances in step 4 for
5 the same reasons.

For this value C0, the operating point is then calculated for each partition or part-circuit in a further step 6, in which the required coupling values, that is to say the values for the
10 coupling points or interfaces of adjacent partitions being exchanged and included in the calculation of the operating points of adjacent partitions.

In this process, a partition which will be called "master" in the
15 text which follows can advantageously take over the control of the charging process for reasons of efficiency. The master then determines the initial value C0 for the capacitances, and it is also conceivable to predetermine the initial value externally, for example by the user. This value C0 is then transferred to all
20 other partitions, called slaves in the text which follows. Following this, the operating point is calculated both in the master partition and in all slave partitions, during which process, naturally, the full source vector, which represents the energy sources existing in the circuit, is present at the circuit.

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Starting from an overall problem to be solved

$$X = (m, s_1, \dots, s_p)$$

30 where m is the unknowns of the master,

p is the number of partitions,

s_i is the unknowns of partition i,

the charging process leads to the system of differential equations,

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Figure 1

(a) **Pre-Test**: A bar chart showing scores for Pre-Test across five categories: English (80), Mathematics (75), Science (65), Social Studies (70), and Art (60). The Y-axis ranges from 0 to 100.

(b) **Post-Test**: A bar chart showing scores for Post-Test across five categories: English (90), Mathematics (85), Science (75), Social Studies (80), and Art (70). The Y-axis ranges from 0 to 100.

(c) **Improvement**: A bar chart showing improvement scores across five categories: English (10), Mathematics (10), Science (10), Social Studies (10), and Art (10). The Y-axis ranges from 0 to 100.

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$$f_i(s_i^{k+1}, m_n^{k+1}, t_i^{k+1}) + \frac{1}{h} D_i((s_i^{k+1}, m_i^{k+1}) - (s_i^k, m^k)) = 0$$

where f_i and D_i are the corresponding equations and matrices for the slave "i". This non-linear equation can also be calculated by means of the Newton method and not all iteration steps have to be necessarily performed to convergence.

The results of the slaves are then inserted into the system equations of the master whereupon the master can calculate the expression m_{n+1}^{k+1} .

In a next step 7, a new value " C_{new} " for "C" is determined by the master and the slaves can also make suggestions. To achieve the aim, namely a value for "C" tending to zero or, respectively, less than a predetermined value ϵ , and thus a calculation of the original circuit, the choice of the new value " C_{new} " for "C" is made dependent on the difficulty of calculating the preceding step with the value " C_{old} " for "C".

In this context, various procedures are conceivable, for example the choice of " C_{new} " in dependence on an analysis of the number of iteration steps which the master needed for calculating the non-linear system of equations for the preceding value " C_{old} " for "C":

$$C_{new} = \begin{cases} C_{old}/2 & \text{is } n < n_1 \\ C_{old} & \text{is } n_1 \leq n \leq n_2 \\ C_{old} \cdot 2 & \text{is } n_2 > n \end{cases}$$

where "n" is the number of iterations of the master and "n₁" "n₂" are the parameters predetermined by the user. Naturally, instead of halving or doubling "C_{old}", respectively, other strategies for reducing or enlarging "C_{old}" are also possible. Additionally, the number of iteration steps needed by the slaves or slave partitions for solving their non-linear system of equations can also be taken into consideration, for example through the choice of

$$n = \max \left(n, \sum_{i=1}^n n_{i, \text{slavel}}, \dots, \sum_{i=1}^n n_{i, \text{slavep}} \right)$$

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where $n_{i, \text{slavej}}$ is the number of iteration steps of slave j, during the i-th iteration of the master. It must be noted in this context that the choice of a value for "C" only affects the efficiency of the method not the operating point itself.

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After a value for "C" of less than or equal to a predetermined value e has been reached, the calculation is terminated at branch 5 and the value for C can be set to "0" in a last step. The operating point of the original circuit is thus found as result 8 and can be output via output units such as for example, a screen, printer or the like and/or stored in a memory as basis for further analyses of the circuit.

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Due to the method according to the invention, an operating point of a very large electrical circuit can be advantageously calculated in parallel by a multiplicity of computers or processors and the disadvantage of known parallel types of calculation, namely lack of convergence with unfavorable starting values can be avoided. Due to the parallel calculation, the expenditure for calculation with regard to iteration steps and

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setting a value for "C" step by step, can be kept within tolerable limits due to the distribution to a number of processors.

The operating point thus calculated is then used as basis for
5 further analyses, for example the alternating-current analysis of
a circuit.